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Work by D.E. Pritchard and his collaborators is summarized here




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Annual Summary Progress Report 0695
Office of Naval Research Contract # N00014-83-K-~~0095~~
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## Pritchard Group: Atom Trapping Progress 1983 -- 1989

### Traps

We have demonstrated two atom traps — one magnetic [BLM87] and one using light forces [RPC87]. In each case ours was the *second* trap of that type, embodying significant new conceptual contributions which permitted tremendous advances over the previous trap of that type (in each case by $\sim 10^5$ in number trapped, and $10^2$ in time trapped). Both of our designs have been used without improvement by other groups; [HKD87] and [VBJ88] for the magnetic trap, and [SST89, SWW89] for the light force trap. Meanwhile, only one new trap has been demonstrated [GLJ88], a light trap which performed less well than ours [RPC87]. This suggests that major advances in atom traps will no longer appear with regularity.

### Cooling

Our proposal for cyclic cooling [PRI83] was the first cooling scheme designed to cool below the Doppler limit. Our discussion of phase space optical pumping [PHB87], which can cool below the recoil limit, was also seminal. So far we have succeeded in applying only Doppler cooling to our trapped atoms.

Several other groups have demonstrated sub-Doppler, and even sub-recoil cooling [LWW88, SWU89, AAK88], but in gasses or one-dimensional beams, not traps. Interestingly, the current explanations of the sub-Doppler cooling invoke a serendipitously occurring type of cyclic cooling.

### Spectroscopy of Trapped Atoms

Our rf spectroscopy [MHB88] and laser spectroscopy of trapped atoms remains unique. The main emphases in this work has been on diagnostics and manipulating the atoms. We showed that the atoms originally trapped are so hot that they are very nearly evenly distributed in phase space, but that they can be cooled to ~ 2 mk by Doppler cooling.

## Cold Collisions

Our observation of collisional loss of atoms in a light trap [RPC87] suggested that the laser excitation was involved in these collisions. In collaboration with Alan Gallagher

at JILA, we have developed a semi-classical theory of collisions in a weak near-resonant laser field [GAP89]; it is the first to consider the effects of spontaneous decay during the collision. Our theory treats absorption of near resonant photons to the attractive excited potential curve which dissociates to a pair of atoms, only one excited. This potential curve has a long range resonant dipole-dipole interaction which decreases as $R^{-3}$, the strongest interaction potential between neutral atoms. Consequently the trap lasers, typically detuned from resonance by one natural linewidth (10 MHz for Na) excite atom pairs with separations $R \geq 800$ Å! With only 1 mK of kinetic energy, these atoms travel only ~ 150 Å in one spontaneous lifetime, rarely surviving to the region $R < 50$ Å where trap loss collision processes can occur (ie. those which are sufficiently exoergic to expel atoms from the trap, causing the observed loss of trapped atoms). Our theory therefore assumes that the laser excites pairs of *stationary* atoms whose separation subsequently evolves due to the strong attractive force in the excited state.

This theory predicts that trap loss should grow with detuning since this causes the laser to excite atom pairs at smaller internuclear separations where the attractive force is strong enough to pull them into the region of strong interaction before they decay spontaneously. We found that previous suggestions that spontaneous decay in this region would be sufficiently red-shifted so that the energy difference between the absorbed and emitted photons (which is converted to translational energy) would expel the atoms from the trap [PRI86, VIG86] missed a much larger effect: we predict that fine structure changing collisions (which also liberate trap-expelling energy) will be the dominant loss mechanism in $Na-Na^*$ collisions.

Recently the frequency dependence for trap loss has been measured for Cs [SWM89] — it is in satisfactory agreement with the predictions of our theory for detunings from 0.3 to 1.5 GHz, but the theory becomes inapplicable (and inaccurate) closer to resonance (ie. for $\delta_v \leq 0.2$ GHz).

**Collective Effects**

So far the idea of doing Bose Einstein condensation in a trap remains an elusive dream. If it is done soon it will be done with hydrogen. Our only contribution to this area is a calculation of the critical behavior of BEC in various traps. We showed that the type of trap strongly affects the critical number needed for BEC, and also influences the thermodynamic behavior - eg. whether or not there is a discontinuity in the specific heat [BPK87].

**People**

No assessment of the significance of our research program is complete without mentioning our most important product: people. Four people have "graduated from" our trapping experiments (Bagnato, Lafyatis, A. Martin, and E. Raab). Bagnato won Brazil's

"Young Physicist of the Year" award in 1988, and Lafyatis has been named a Presidential Young Investigator. The P.I.'s group has been very productive of good people over the years, and several have made contributions to trapping work at NIST (W. Phillips. postdoc in 1976-77, P. Gould, Ph.D. 1986 and A. Migdall, Ph.D. 1984). The first authors on 4 of the first 6 papers demonstrating atom traps received their PhD's in the P.I.'s group.

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